Applied Occupational and Environmental Hygiene
Volume 18(6): 466–478, 2003

1047-322X/03 $12.00 + .00
DOI: 10.1080/10473220390209530

Asbestos Release During Removal of Resilient Floor Covering Materials by Recommended Work Practices of the Resilient Floor Covering Institute

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The release of asbestos during maintenance and removal of resilient floor covering is of concern to health professionals and many regulators. This study assesses the asbestos levels observed during removal of resilient floor covering products using the "Recommended Work Practices" (1995) of the Resilient Floor Covering Institute or other methods requiring containment (Controls). The 1995 "work practices" require wet removal or dry heat removal but do not require the use of respirators. Wet removals of sheet vinyl/separated backing, 12″ × 12″ vinyl asbestos tile/mastic, and 9″ × 9″ asphalt tiles/mastic were conducted and the air was sampled during each procedure. Settled dust samples were collected at the sites of RFCI square tile removal and pieces of each type of tile were broken in a mini-enclosure to evaluate asbestos emissions. Analyses of the air samples collected during the removals showed that the RFCI methods did not produce asbestos counts significantly different from the Control methods requiring containment. Only a small number (0.7%) of fibers and structures, counted and measured by Analytical Transmission Electron Microscopy, would have been counted using the rules for Phase Contrast Microscopy in the 7400 method specified by Occupational Safety and Health Administration regulations. This indicates workers in similar situations without respirators are likely to have unknown exposure levels. A high percentage of these fibers and structures are 5 micrometers or less in length, smaller than 0.5 micrometer in diameter, and are easily inhaled. The RFCI air sample and settled dust data may cause regulators to consider requiring respiratory protection, cleanup procedures, and methods to control asbestos migration. Other areas that might be addressed are clearance levels and their measurement, removal area size, bulk sample analysis by transmission electron microscopy if polarized light microscopy reports less than 1 percent asbestos, better worker exposure evaluation, and supervisor/worker training in accordance with the Model Accreditation Plan.

Keywords Asbestos, Floor Covering, Abatement, RFCI Methods, Electron Microscopy, Phase Contrast Microscopy

The possibility of the inhalation of asbestos fibers, during and subsequent to the removal of floor covering materials, is one of the major concerns of environmental consultants, professional engineers, certified industrial hygienists, researchers, occupational medicine physicians, workers, and, most importantly, regulators. All states have an agency charged with protecting the health of their citizens by adopting federal standards as a minimum. Their standards may be more stringent, except for rules directly protecting workers unless the state is an OSHA contract state. The OSHA Asbestos Exposure in Construction Regulation 29 CFR 1926.1101[1] is based on the types of materials and the nature of the work rather than the operation being conducted. The asbestos permissible exposure limit (PEL) was reduced to 0.1 f/cc for an 8-hour time weighted average (TWA) and the short-term excursion limit, re-designated excursion limit (EL), is 1 f/cc for a 30 minute TWA.

The concept of specific work practices to be used with certain types of materials was introduced. One of these specific provisions was resilient floor covering, which is addressed as Class II work. Any resilient floor covering material installed in 1980 or earlier is defined as presumed asbestos containing material (PACM) and is identified as asbestos containing material (ACM) subject to sampling and analysis by technically feasible means to establish that the material in question does not contain greater than 1 percent asbestos. The analysis is to be by the polarized light microscopy (PLM) protocol of the National Voluntary Laboratory Accreditation Program (NVLAP),[2] which is administered by the National Institutes of Science and Technology (NIST). This OSHA regulation[1] specifies that resilient floor materials are to be removed intact where

possible, regulated areas are to be established and it also allows the use of a negative exposure assessment based on personal sample data from projects "closely resembling the current project."

Sheet vinyl floor covering does not contain asbestos in the walk surface but the backing frequently is asbestos felt (paper) and contains in our experience 40 percent to 75 percent asbestos. The asbestos content of square tiles is usually in the range of 8–50 percent. The asbestos is mixed throughout the tile and thus is subject to wear and abrasion during normal use.[3–7] Stripping and buffing operations have been documented as producing airborne fibers.[4,8–11] OSHA regulations[1] specify the use of a low-speed buffer (<300 RPM) and the least abrasive pad.

It is difficult to determine asbestos content by PLM[12–17] in square asphalt and vinyl asbestos floor tiles. In a policy guidance document[18] the EPA has stated that in the event flooring materials are reported at 1 percent or less by PLM[12–14] analysis, the asbestos content should be determined by transmission electron microscopy bulk analyses methods.[12–14] The NVLAP[2] accreditation program requires accredited laboratories to insert a disclaimer in the laboratory report stating that "PLM is not a valid method for determining asbestos content in floor covering materials and if the analysis is reported at 1 percent or less, analytical transmission electron microscopy (ATEM) bulk methods should be used." The EPA has published an ATEM analysis method[12–14] for floor tiles and other small fiber-containing materials.

The asbestos used in flooring materials is Grade 7—Shorts and Floats. The dimensions of this material are very small and may not be resolvable by the PLM microscope. Also, fibers may be obscured by the matrix. It is easy to understand why analysis of floor tiles is very difficult by PLM when you investigate the manufacturing methods and the specifications[5–8,16,17] for floor covering materials. The common procedure for the manufacture of resilient floor covering is to use Banbury mixers[5] that are heated. Raw materials are mixed by a tumbling action. The specifications generally call for approximately 25 percent asbestos. This may be more or less in some cases. Shorts and Floats are the cheapest asbestos materials. A marketing person at an asbestos company advised that Grade 7 is no longer sold and in fact is buried by the mill.[19] The asbestos, which is added to the flooring materials, is serving as a binder rather than improving resistance to wear or providing friction. At the time of the mixing, different materials may be added and the color and patterns are established.

The fact that the dimensions of the asbestos fibers used in the manufacturing of flooring are so small accounts for the very low personal exposures based on analyses of flooring worker air samples by phase contrast microscopy (PCM) in accordance with the NIOSH 7400 protocol.[20] Many ultrafine fibers are not counted[9,21] due to the resolution (0.2–0.25 μm) of the phase contrast microscope and due to the count protocol, which provides that only fibers longer than 5 μm with a 3:1 or greater length-to-width ratio will be counted. This is the definition of a fiber used by U.S. OSHA (29 CFR 1926.1101 [b]).[1] The end result is the PEL of 0.1 f/cc 8 hr TWA is seldom exceeded in resilient flooring removals. In contrast, clearance samples under the Asbestos Hazard Emergency Response Act (AHERA) rules[22] are collected on smaller-pored filters (0.45 μm or 0.4 μm) and are analyzed by the AHERA ATEM protocol counting structures >0.5 μm long to 5 μm long and ≥5 μm long with a ≥5:1 aspect ratio.

Many studies[23–28] confirm asbestos exposure causes disease. The premise[29] that only long fibers (≥10 μm) are going to cause asbestos disease becomes very difficult to rationalize in light of the many research studies that find that a preponderance of fibers at autopsy left in lung tissue, pleural plaques, and lymph nodes of persons who have occupational exposure to asbestos are shorter than 5 μm in length.[23,29–33] OSHA was advised by the Health Effects Institute[34] in 1993 that personal exposure analysis by the NIOSH 7400 protocol[20] was not a valid way to evaluate a person's exposure and a recommendation that at least some samples should be analyzed by AHERA ATEM protocols[22] was made.

The Asbestos Hazard Emergency Response Act Regulations, 40 CFR 763 Subpart E,[22] require public schools to inspect for friable and non-friable ACM. Areas having settled dust from delamination are required to be cleaned to abate potential exposure from occupant activities that may re-entrain settled dust, allowing it to be inhaled.[35,36] The area where resilient floor covering is removed by RFCI methods[37,38] is required by settlement agreement[39] with OSHA to be isolated from other areas.

It is also common to find reports and research papers that state analyses were by TEM but they do not specify the protocol used.[40] There is an ATEM procedure for air samples using the protocol designated NIOSH 7402.[41] This TEM protocol counts asbestos and non-asbestos fibers that would be counted with a light microscope. The difference in the protocols is use of X-ray Energy Dispersion Spectroscopy (XEDS) and Selected Area Electron Diffraction (SAED) to identify those fibers meeting the asbestos count criteria. The "percent asbestos" in the sample is then used to reduce the PCM count. The obvious problem with this method is that it underreports the amount of asbestos in the samples because it ignores all fibers ≤5 μm and all those fibers longer than 5 μm but less than 0.25 μm in diameter.

STUDY DESIGN

The procedures to be investigated are those for the removal of sheet vinyl, vinyl or asphalt floor tiles, and cutback mastic using amended water or an adhesive removal product allowed in "Recommended Work Practices for the Removal of Resilient Floor Coverings."[37,38] In this study Abatix 007 was the removal product used. An additional area at each site was designated for "control removal" utilizing the aggressive methods normally used in removals by abatement contractors. In each case the

goal was to produce a clean flat surface ready to accept new flooring. Some residual mastic always remained in the pores of the concrete sub-floor.

The following general criteria[21] were established for all field investigations during the study:

1. Locations for the investigative procedures were evaluated by a licensed asbestos inspector. No sites were used that had any friable ACM or damaged ACM present in the area.
2. The six removal workers were EPA Model Accreditation Plan (MAP)[42,43] accredited and were experienced in asbestos abatement. The same workers were used at all sites.
3. Each site was cleaned by high efficiency particulate air (HEPA) vacuum and/or wet wiping. Five baseline samples were collected prior to initiating any preparation work. Sample volumes were between 560 to 1560 liters to avoid overloading. The baseline air samples were collected and analyzed by PCM, NIOSH 7400, Issue 2, A counting rules,[20] and ATEM Yamate Level II,[44] and in each location revealed a lack of asbestos contamination.
4. Three bulk samples of sheet vinyl or floor tile/mastic per site were analyzed by PLM[2,12,14] and the Chatfield ATEM Method.[13]
5. Each work site had critical barriers installed and was under a differential pressure of –0.02 inches water column. All sites had full inverted containment consisting of a single layer of 4 mm polyethylene on the walls and ceiling. During each specific RFCI procedure, the work area within the negative pressure enclosure was sealed using polyethylene partitions sealed to the floor and ceiling and polyethylene double flap openings taped closed so there was no air circulation inside. The air flow was checked using smoke tubes, and there was no detectable flow observed. Each of the control investigations was conducted with four air changes per hour in the work area. All locations had decontamination facilities.
6. Five area air samples were collected in the work area involved during each procedure. Four samplers were located about four feet from the corners of the room and a fifth was placed in the center of the room. Sample volumes in each of the work areas varied due to the visual loading of the filters and/or the time required for the procedures to be conducted. All air samples were collected on 0.45 μm mixed cellulose ester (MCE) filters in 25 mm conducting cassettes with 50 mm extension cowls at a flow rate of 1 to less than 10 liters per minute. All flow rates for air samples were measured at the start and at the completion of the sampling period using an Asbestos Analytic Rotameter that was calibrated prior to this project using a Gilibrator electronic calibrator as the primary standard. All air samples were analyzed by NIOSH 7400 Method, Issue 2, Counting Rules A,[20] and by ATEM, Yamate Level II Method.[44]
7. Outside air samples were taken at negative air unit discharges and areas outside the containment and were analyzed by both PCM and ATEM using the procedures cited in item 3 above. Asbestos contamination was not detected.
8. Following the completion of the procedures at each work site, each area was cleaned by HEPA vacuum and wet wiping. Air samples for clearance analysis were collected by aggressive methods and were analyzed by ATEM in accordance with 40 CFR 763 Subpart E, Appendix A[22] at an NVLAP-accredited laboratory.
9. After clearance was achieved, all remaining polyethylene was removed and disposed of as ACM and the areas were made available for re-occupancy following final cleaning.
10. The Texas Department of Health is not an OSHA enforcement agency and personal samples were not a part of the study. Personal samples were collected by the workers' employer and no levels greater than the PEL or EL were detected.

The removal of sheet vinyl (Figure 1) in a hospital home medical equipment store was conducted in Areas 1 and 2 in accordance with the RFCI work practices.[illegible] The workers slit the vinyl into 8" strips and attempted to roll it while cutting, with short-handled scrapers, at the wet nip line where it separated from the mastic and asbestos felt backing. This backing was then removed from the floor using more amended water and short-handled scrapers. The vinyl strips and pieces were placed in disposal bags. Scrapings were collected with wet wipes and a wet HEPA vacuum. The vinyl broke up readily because it was brittle and well adhered to the floor. The use of short-handled scrapers required the workers to be on their knees or bent over while they worked and thus close to the asbestos emission sources. The workers did not walk on the concrete sub-floor until it was dried, HEPA vacuumed again, and wet wiped (see step 8 above). Area 3 was the control area where more aggressive measures with long-handled scrapers and amended water were used to remove the vinyl, felt, and mastic at the same time. The area was cleaned as above. Areas 1, 2, and 3 were approximately 130 ft² each.

The 12" × 12" vinyl tiles (Figure 2) were located in a commercial building. They were removed in Areas 1 and 2 according to RFCI methods[37] using amended water and short-handled scrapers. The workers again had to work on their knees as they tried to remove the tile in as near an intact state as possible. Area 3 was the control area where the tiles and mastic were removed together by long-handled scrapers and amended water. The tile fragments and scrapings in each area were picked up and the areas were cleaned with wet HEPA vacuums. They were allowed to dry, HEPA vacuumed again, and wet wiped until clean. Area 1

FIGURE 1
Sheet vinyl removal—RFCI method. (Hospital home medical equipment store. Area 1).

was approximately 240 ft^2. Area 2 was 200 ft^2, and Area 3 was 700 ft^2.

The 9″ × 9″ asphalt tiles (Figure 3) were in a high school cafeteria. The tiles in Areas 1 and 2 were removed wet with amended water and short-handled scrapers using RFCI methods.[37] The mastic in Area 1 was removed wet with Abatix 007 solvent and the resultant slurry was picked up with wipe rags. The cleaning was completed using a HEPA vacuum and additional wiping with rags and clear water. The mastic in Area 2 was removed with amended water. Area 3 was the control area where long-handled scrapers and the more aggressive measures described for Area 3 of the commercial building were used. Areas 1 and 2 were each approximately 150 ft^2 and Area 3 was 200 ft^2.

Settled dust samples[3] were collected from 1 ft^2 areas approximately 16 h after the removal of 12″ × 12″ tiles and mastic in RFCI Area 1 of the commercial building and just prior to final cleaning. Filtered de-ionized water was used to suspend the dust on two horizontal surfaces and a micro-vacuum[45] was used to collect dust on a dry vertical surface. The liquid samples were drawn into flasks using personal pumps. The micro vacuum collection[45] was on a 0.45 μm pore size MCE filter in a conducting lab cassette with a Tygon tubing extension cut at 45° connected to the inlet opening in the end cap. The same procedures were conducted in RFCI Area 2 in the high school cafeteria following removal of 9″ × 9″ tile and mastic.

An additional investigation was conducted inside a 4 ft × 3 ft × 4 ft mini-enclosure to determine the extent of asbestos emission due to tile breakage. Square tiles from each of the sites used in the study were placed on a slightly raised rack and broken with a single blow from an automobile body repair hammer. The tile pieces were allowed to remain without disturbance during the breaking. There was no movement of the tiles to cause abrasion, and there was no mastic adherent to these tiles. Closed loop air samples (510–601 L) were taken inside the enclosure during the entire process. After completion, the air in the mini-enclosure was exchanged and the entire enclosure was HEPA vacuumed and wet wiped before the next samples were broken.

FIGURE 2
12″ × 12″ vinyl asbestos tile—RFCI method. (Commercial building, Area 2).

FIGURE 3
9″ × 9″ asphalt tile removal—RFCI method. (High school cafeteria, Area 2).

ANALYTICAL PROCEDURES

Bulk Sample Analysis

Bulk samples were analyzed by both PLM and ATEM. The PLM procedure is described in 40 CFR 763, Subpart F, Appendix A.[22] The ATEM analyses were performed according to Chatfield.[13] PLM results are reported as area percent and ATEM results as weight percent.

Phase Contrast Microscopy

Phase contrast microscopy following NIOSH 7400, Issue 2[20] was used to analyze portions of the 0.45 μm MCE filters for later comparison with ATEM results. One-fourth of each filter was analyzed at 400× and fibers longer than 5 μm with aspect ratios equal to or greater than three were counted using the NIOSH 7400 "A" rules.[20] Results are reported as fibers per cc.

Analytical Transmission Electron Microscopy

ATEM counts were obtained on the above filters using the Yamate Level II protocol.[44] In brief, portions of the filters were collapsed on glass slides with acetone vapor and plasma etched until 10 percent of the surface was removed. They were carbon coated in a vacuum and small squares were placed on calibrated 100 mesh grids. The MCE plastic was removed in an acetone condensation washer. The samples were examined at a magnification of 16,000× or 20,000× for asbestos structures, most of which consisted of multiple asbestos fibers counted as a single structure (Figures 4a through 4d). One 100-mesh grid square was analyzed on each of three grids. To be counted, a structure had to be or have an asbestos fiber with a 5 to 1 or greater aspect ratio and be at least 0.5 μm long or greater. Selected area electron diffraction (SAED) and X-ray energy dispersive spectroscopy (XEDS) were used to confirm all asbestos and non-asbestos structures. The first 33 structures from each grid were measured and categorized as fibers, bundles, clusters, or matrices according to AHERA.[22] The remainder were categorized morphologically and recorded as asbestos structures greater than or equal to 0.5 μm to less than 5 μm, or greater than or equal to 5 μm in length. The data were made to conform to the AHERA counting rules[22] and were reported using the AHERA guidelines.[22] The AHERA protocol[illegible] was used for collection of all clearance samples.

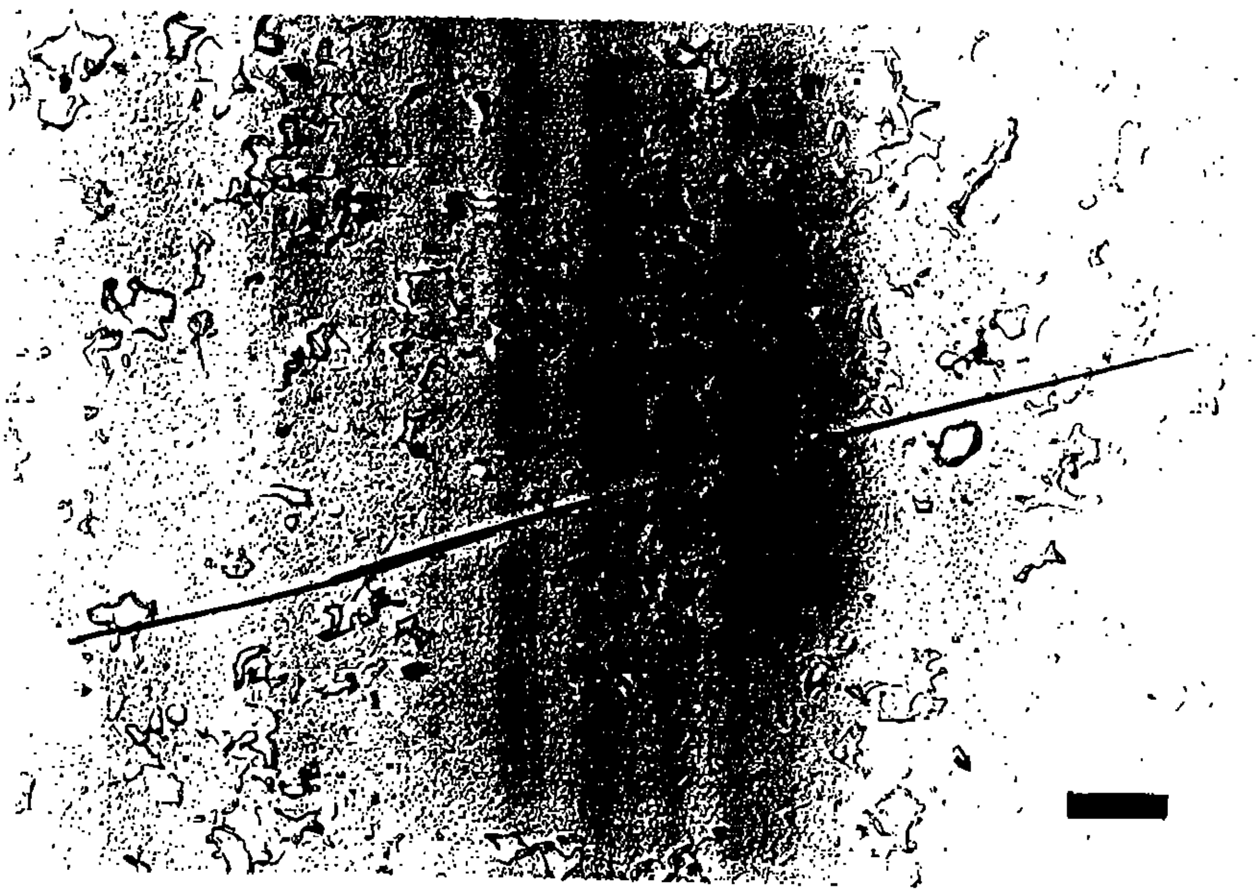

FIGURE 4a
Chrysotile fiber, (12" × 12" vinyl asbestos tile removal by RFCI method; TEM, bar equals 1 μm).

FIGURE 4b
Chrysotile bundle, (9″ × 9″ asphalt tile removal by control method; TEM, bar equals 1 μm).

Settled Dust Samples

These samples were collected in one of two ways. In the first case, water pre-filtered through 0.2 μm pores was used to thoroughly resuspend settled abatement dust on horizontal 1 ft^2 areas. Aliquots were removed, filtered through 0.45 μm MCE filters, dried, and prepared for ATEM by the direct carbon extraction replica technique described above. The second case involved the removal of settled dust from 1 ft^2, vertical surfaces

TABLE I
Sheet vinyl removal—Hospital home medical equipment store bulk sample analysis

Description	# of samples	PLM	ATEM
Sheet vinyl, light green	3	Vinyl layer: ND Backing: 60–65%	ND 70–80%

Air sample analysis

Location	# of samples	Sample volume (liters)	PCM f/cc	ATEM total s/cc	ATEM ≥ 0.5 to < 5 s/cc	ATEM ≥ 5 s/cc
Area 1 RFCI	5	1200	0.011–0.029	0.806–0.860	0.437–0.584	0.254–0.369
Area 2 RFCI	5	750	0.024–0.034	0.562–0.697	0.284–0.426	0.264–0.291
Area 3 control	5	585	0.024–0.031	0.675–0.902	0.204–0.393	0.482–0.573

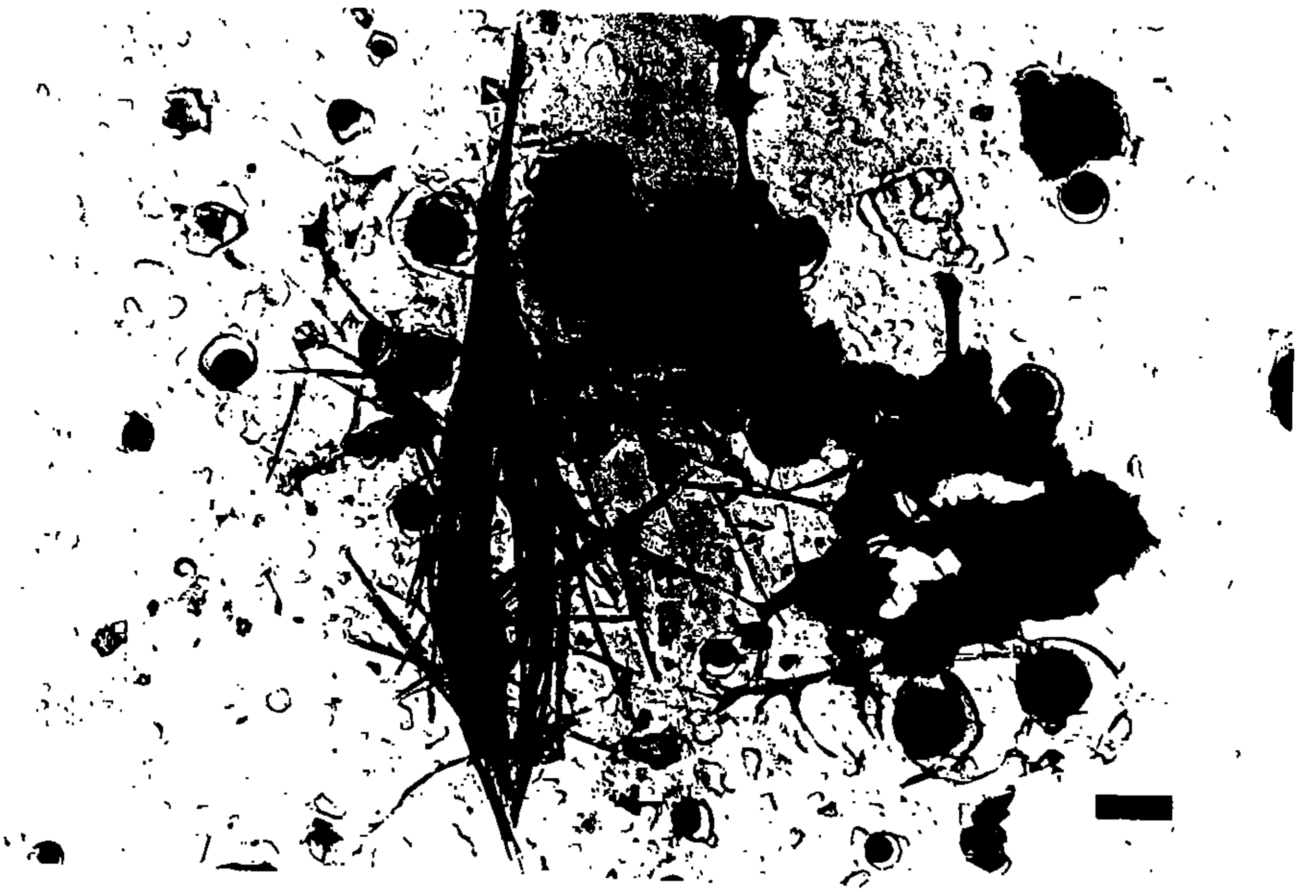

FIGURE 4c
Chrysotile cluster. (Sheet vinyl removal by RFCI method: TEM, bar equals 1 μm).

using the ASTM D5755.95 micro-vacuum method.[35,36] The 0.45 MCE filters were prepared for ATEM analysis as above. The data were reported as structures per square foot.

Statistical Analysis

Data were tested for significant differences, after square root transformation, with the t test for independent samples.

RESULTS

Table I tabulates the data for the sheet vinyl investigation. The PLM bulk analysis[2] reported the vinyl layer as none detected (ND) and the felt backing as 60–65 percent chrysotile. The bulk analysis by ATEM[13] reported the vinyl layer as none detected and the felt backing as 70–80 percent chrysotile. The laboratory results of fiber levels by PCM for removal of sheet vinyl

TABLE II
12″ × 12″ vinyl asbestos tile removal—Commercial building bulk sample analysis

Description	# of samples	PLM	TEM
12″ × 12″ tan tile	3	ND	
Black mastic		5–8%	4–8%

Air sample analysis

Location	# of samples	Sample volume (liters)	PCM f/cc	ATEM total s/cc	ATEM >0.5 to <5 s/cc	ATEM >5 s/cc
Area 1 RFCI	5	1560	<0.003–0.005	0.035–0.085	0.023–0.294	0.012–0.036
Area 2 RFCI	5	840	<0.006–0.009	0.066–0.236	0.035–0.147	0.031–0.089
Area 3 control	5	1480	0.005–0.012	0.081–0.127	0.051–0.083	0.025–0.044

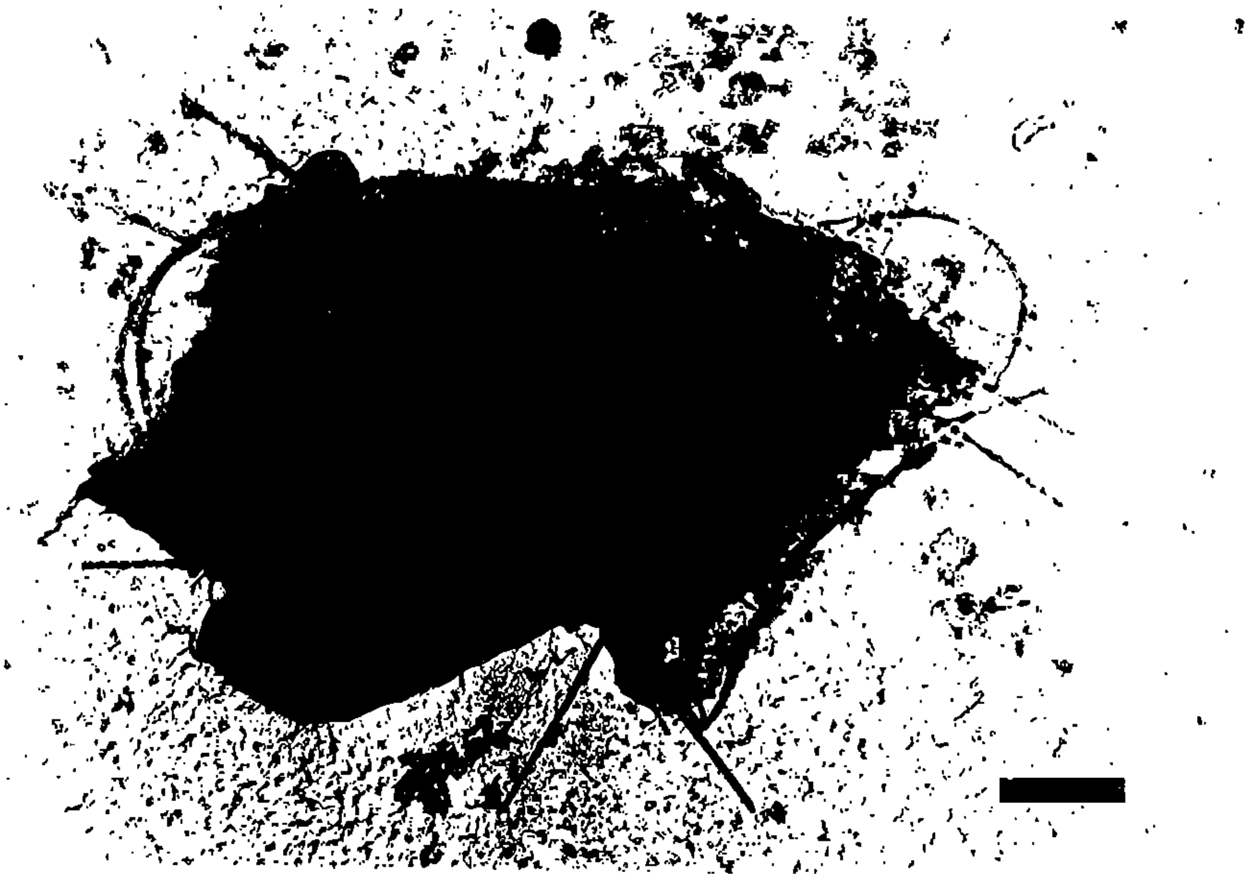

FIGURE 4d
Chrysotile matrix. (Sheet vinyl removal by RFCI method: TEM, bar equals 1 μm).

using RFCI Work Practices[37] ranged from 0.011 to 0.048 fibers per cc. Inside the control area the range was from 0.024 to 0.031 fibers per cc. None of these samples exceeded the Excursion Limit[1] or Permissible Exposure Limit.[1] The range of asbestos structures per cc reported by (ATEM) Yamate Level II Method[44] was 0.562 to 1.002 structures per cc for the RFCI Work Practices.[37] The range inside the control area was reported at 0.675 to 0.902 asbestos structures per cc. Only 7 percent

TABLE III
Asphalt tile removal—High school cafeteria bulk sample analysis

Description	# of samples	PLM	TEM
9" × 9" beige tile	3	1–3%	12–19%
Black mastic		7–10%	

Air sample analysis

Location	# of samples	Sample volume (liters)	PCM f/cc	ATEM total s/cc	ATEM ≥0.5 to <5 s/cc	ATEM >5 s/cc
Area 1 RFCI	5	560	0.011–0.014	0.099–0.355	0.071–0.294	0.028–0.061
Area 2 RFCI	5	850	0.008–0.012	0.138–0.387	0.104–0.322	0.034–0.065
Area 3 control	4	735	0.011–0.015	0.240–0.332	0.148–0.174	0.092–0.179

TABLE IV
RFCI mastic removal—High school cafeteria

Location	# of samples	Sample volume (liters)	PCM f/cc	ATEM total s/cc	ATEM ≥0.5 to - 5 s/cc	ATEM ≥ 5 s/cc
Area 1 Abatix 007	5	567	0.048–0.075	1.319–1.749	0.859–0.120	0.460–0.752
Area 2 Amend. water	5	750	0.011–0.018	0.094–0.184	0.083–0.161	0.017–0.061

of the fibers and bundles found and measured by ATEM[44] in the RFCI Work Practices[37] areas were counted applying the NIOSH 7400 PCM[20] rules and resolution to the ATEM data and only 5 percent were counted in the control area. These data indicated the PCM method of analysis greatly underestimated the level of actual asbestos fibers.

Table II tabulates laboratory results for the removal of 12″ × 12″ vinyl asbestos tile by RFCI and Control methods. The bulk PLM Analysis of the tile was reported none detected and the mastic was 5–8 percent chrysotile. ATEM Bulk Analysis reported the tile as 4–8 percent chrysotile. The range of fibers reported by PCM for the RFCI removal in the two areas was less than 0.003 to 0.009 fibers per cc. The PEL and EL were not exceeded. The ATEM results for these areas were 0.035 to 0.236 asbestos structures per cc for the RFCI removal. The results for the control removal were 0.005 to 0.012 fibers per cc by PCM and 0.081 to 0.127 asbestos structures per cc by ATEM. Only 2.5 percent of the fibers and bundles found and measured by ATEM in the RFCI areas were counted applying the PCM rules to the ATEM data and only 2 percent of those in the control area were counted. Again, PCM greatly underestimated the asbestos fiber level due to the count protocol and resolution.

Table III presents results of the investigation involving 9″ × 9″ asphalt tiles and mastic. The bulk analysis of tile by PLM reported 1–3 percent and the mastic was 7–10 percent. The ATEM bulk analysis reported the tile at 12–19 percent chrysotile. The range of fibers reported by PCM for the two RFCI removal areas was 0.008 to 0.014 fibers per cc. The PEL and EL were not exceeded. The ATEM range was 0.099 to 0.387 structures per cc for RFCI removal. The PCM level reported for the control method was 0.011 to 0.015 fibers per cc and the ATEM result was 0.240 to 0.332 asbestos structures per cc. Two and one-half (2 1/2) percent of the asbestos fibers and bundles counted and measured by ATEM were counted by applying PCM rules to the ATEM data in the RFCI area and none were counted in the control area.

Table IV presents mastic removal data obtained after the 9″ × 9″ tile removal. In mastic removal Area 1, using the mastic remover Abatix 007, results were 0.048 to 0.075 f/cc by PCM and 1.319 to 1.749 asbestos structures per cc by ATEM. One-half of one (0.5) percent of the fibers and bundles counted and measured by ATEM were counted by applying PCM rules to the ATEM data during mastic removal. Again, it was seen that PCM greatly underestimated the actual asbestos fiber level due to the count protocol.

The fiber levels reported by PCM analysis during removal of mastic in Area 2 by amended water were 0.011 to 0.018 f/cc and 0.094 to 0.184 asbestos structures per cc by ATEM. The levels by PCM were lower by a factor of four when using amended water compared to Abatix 007 mastic remover and lower by a factor of eleven with ATEM.

Table V tabulates the results of settled dust samples reported as structures per square foot by ATEM analysis.[44] The level of asbestos on the horizontal surfaces ranged from 14 million to 25 million structures per square foot. The level on the vertical surfaces was from <1100 to 4800 structures per square foot. These data indicated asbestos dust settled more readily on horizontal surfaces than on vertical surfaces. It is possible that the asbestos sampling on the vertical surfaces, using the micro-vacuum method, was incomplete because other fibers may have been held on the surface by static charges or lockdown.

The results of the ATEM analyses of air samples collected inside a mini-enclosure while tiles were broken by striking a single blow with an automobile body hammer were as follows: Both 12″ × 12″ and 9″ × 9″ tiles were tested. In each case the tiles were allowed to lie and were not further disturbed. The asbestos released, measured by ATEM, was at or less than the detection limit (<0.0058 str/cc). This probably was due in part to the binding of the matrix and the fact that no disturbance of the pieces occurred after breaking.

TABLE V
ATEM settled dust results—Horizontal surfaces, water collection

Description	Sample	Str/ft², (millions)
Commercial building, post-RFCI	TW—01	25
	TW—02	20
High school cafeteria, post-RFCI	NW—1A	23
	NW—1B	14
Vertical surfaces, micro-vacuum collection		
Commercial building, post-RFCI	TV—01	<1100
	—	—
High school cafeteria, post-RFCI	NV—301	4800
	—	—

CONCLUSION

The following information was obtained from the study. PCM and ATEM air analyses (Tables I, II, and III) revealed asbestos emissions produced by the RFCI and Control methods did not significantly differ from each other at any of the three locations in the study. A possible reason for this is that the materials were firmly adhered to the sub-floor, unlike those more recently installed. Another important finding for both methods was that the ATEM counts for total asbestos structures per cc averaged 22 times greater than the PCM fiber counts on the same filters (Tables I—IV). The ATEM asbestos concentrations obtained during RFCI mastic removal with a commercial mastic remover averaged 11 times those measured during the RFCI removal with amended water (Table IV). Considerable amounts of asbestos dust settled on exposed surfaces during the RFCI tile removal in both locations (Table V). Finally, the PLM bulk sample analyses underestimated the amounts of asbestos in the flooring materials (Tables I–III).

The RFCI method[46] used in our original study[21] produced higher counts than the RFCI methods[37] in the current study because the 1990 RFCI procedures[46] did not require the use of amended water. Since the RFCI procedures[37] cited in the agreed judgment[39] still did not require respiratory protection for the workers or cleanup standards for the work areas or clearance samples, anyone in the areas during either study without a respirator would have inhaled asbestos fibers or structures of respirable dimensions.

The elevated asbestos levels measured during the RFCI and Control sheet vinyl/mastic removals were probably caused by the following:

1. The brittle vinyl broke easily everywhere and was well adhered in the heavy traffic areas because it had been installed for a number of years.
2. Additional effort was often required to remove the residual asbestos felt and mastic from the concrete sub-floor.

The cause of elevated asbestos levels during the removal of square tile/mastic was probably due to one or all of the following:

1. Removal by RFCI or controlled methods resulted in broken pieces of tile abrading each other as they were pushed together by the removal tool.
2. The mastic was abraded as the tile was removed and was further abraded by scraping as other tiles were removed.
3. In those cases where the tile was firmly attached, more aggressive use of the scraper was required to remove these tiles or the pieces of tile from the floor.

The fact that the simple breaking of tiles in the mini-enclosure did not produce enough airborne fibers to be detected by ATEM supports the idea that a major portion of the asbestos emissions were caused by abrasion between tile/mastic fragments and/or by the scrapers. The higher levels of fibers seen during the removal of mastic using organic mastic remover were probably due to the action of the solvent on the binders that were holding the asbestos.

Asbestos structures settled in the work areas (Table V) and, if not contained and cleaned up, would have been subject to re-entrainment by occupant activities. In order to address the protection of human health and the environment the following suggestions are prudent based on the asbestos levels generated during all of these procedures by well-trained, experienced workers.

1. It is important to insure that all employers who remove "intact" flooring materials using RFCI work practices notify the employers of employees who will be working in adjacent areas during the removal and that they isolate the work area by an impermeable barrier, which may include a wall, closed door, or window as required by law. (See paragraph 6, page 9 of Settlement Agreement in the U.S. Fifth Circuit Court of Appeals, June 1, 1995, Azrock Industries, Inc., et al. versus Occupational Safety and Health Administration, U.S. Department of Labor).[39]
2. Require proper cleanup by HEPA vacuum/wet wiping within the removal area and the contiguous areas, if not separated.
3. Establish clearance levels and sample collection methods for all removals by RFCI methods in public, commercial, and industrial buildings. The sample collection should require aggressive methods to be used. The clearance level should be specified as less than 0.005 structures per cc for each sample and all samples collected must be analyzed by the AHERA ATEM protocol[22] and must be reported. It is recommended that larger volumes be collected and larger filter areas be quantified to insure greater accuracy. The recommended minimum sample volume is 1250 liters. The minimum number of samples for clearance should be one for each 500 square feet. Each sample should be collected on 0.45 μm MCE filters in 25 mm diameter conducting cassettes with a 50 mm extension cowl at a flow rate of 1 to <10 Lpm. AHERA[22] regulation clearance standards already apply to public schools.
4. For removals prior to demolition, a clearance level of 0.01 structures per cc by AHERA ATEM protocol[22] is recommended.
5. Regulations should be revised to require all flooring materials to be analyzed by the ATEM Bulk Sample method[11] if samples analyzed by PLM are reported as 1 percent or less asbestos content. An assumption of asbestos content greater than 1 percent is allowed by all federal regulations.

An examination of the PCM and ATEM air sample data from the same filters readily reveals the problems associated with using PCM to estimate asbestos air concentrations in these removal situations. These problems are: (1) all fibers must be counted by PCM, non-asbestos and asbestos, resulting in non-specificity and (2) a very high percentage of the asbestos present is not seen or must be ignored because of the counting rules. The Health

Effects Institute[34] realized these problems with PCM in 1993 when they advised OSHA that at least some samples should be analyzed by the AHERA ATEM protocol.[22] The authors definitely agree with this position.

There is an undetermined quantity of asbestos-containing flooring materials presently installed in buildings throughout the United States. There is no prevailing regulation[47] that prohibits the manufacture and/or importation into the United States of asbestos-containing flooring materials. Most, if not all, domestic manufacturers of flooring materials do not put asbestos in their products at this time. However, with one exception, there is no regulation that prohibits the installation of ACM flooring materials in any facility in the United States.

Texas has recently passed a law prohibiting the replacement of asbestos-containing material after removal in public or commercial buildings with any other ACM.[48] Some school districts have installed new flooring material and wrongly assumed that it would not contain asbestos when, in fact, it did.

Another concern is the residential area. The same ACM materials are found in single-family dwellings and apartment buildings. There is no way to estimate the number of residences that have flooring materials containing asbestos at greater than 1 percent. These are locations where flooring materials are routinely removed without any type of control because as a single family dwelling there are no regulations with regard to accreditation of personnel involved or disposal of the asbestos-containing material. The authors certainly do not advocate trying to apply regulations to single family dwellings but an education program addressing single-family dwellings and possible asbestos contamination is in order.

ACKNOWLEDGMENTS

The authors thank Jay Stone for assisting with sample collection and the Texas Department of Health for funding this research. The Texas Department of Health did not have any direct involvement with the study.

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